Chapter 5

Force and Motion–I

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5-1- 5-5 Newton's First and Second Laws

Learning Objectives

Link attached

5.01 Identify that a force is a vector quantity and thus has both magnitude and direction and also components.
5.02 Given two or more forces acting on the same particle, add the forces *as vectors* to get the net force.
5.03 Identify Newton's first and second laws of motion.
5.04 Identify inertial reference frames.
5.05 Sketch a free-body diagram for an object, showing the object as a particle and drawing the forces acting on it as vectors anchored to the particle.
5.06 Apply the relationship between net force on an object, its mass, and the produced acceleration.
5.07 Identify that *only* external forces on an object can cause the object to accelerate.

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Newton's First and Second Laws

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- A **force**:
  - > Is a “push or pull” acting on an object
  - > Causes acceleration
- We will focus on Newton's three laws of motion:
  - > **Newtonian mechanics** is valid for everyday situations
  - > It is *not* valid for speeds which are an appreciable fraction of the speed of light
  - > It is *not* valid for objects on the scale of atomic structure

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Newton's First and Second Laws

- Before Newtonian mechanics:
  - > Some influence (force) was thought necessary to keep a body moving
  - > The "natural state" of objects was at rest
- This seems intuitively reasonable (due to friction)
- But envision a **frictionless surface**
  - > Does not slow an object
  - > The object would keep moving forever at a constant speed
  - > Friction is a force!

Link attached

Newton's First Law: If no force acts on a body, the body's velocity cannot change; that is, the body cannot accelerate.

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Newton's First and Second Laws

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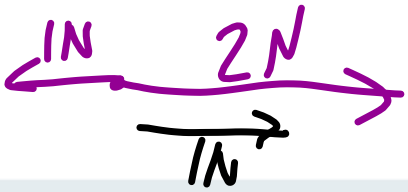
- Characteristics of forces:
  - > Unit: N, the newton; 1 N = 1 kg m/s^2
  - > Acceleration of a mass is proportional to the exerted force
  - > Forces are vectors
- **Net force** is the *vector sum* of all forces on an object
- **Principle of superposition for forces**:
  - > A net force has the same impact as a single force with identical magnitude and direction
  - > So we can restate more correctly:



Newton's First Law: If no *net* force acts on a body ($\vec{F}_{\text{net}} = 0$), the body's velocity cannot change; that is, the body cannot accelerate.

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Newton's First and Second Laws

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- Newton's first law is not true in all frames
- **Inertial frames**:

An inertial reference frame is one in which Newton's laws hold.

- A) a puck sliding along a short strip of frictionless ice: obey laws
- B) Strip is very long, puck would accelerate slightly to observer on ground
- Over *long* distances, the ground is a **noninertial frame**
- In (b), a fictitious force would be needed to explain deflection

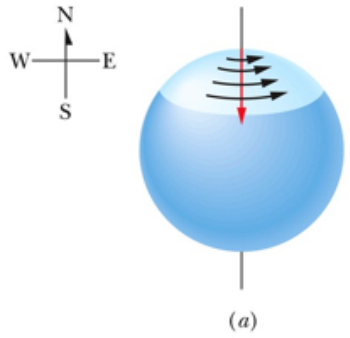
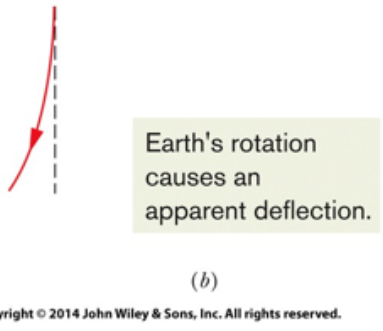


Figure 5-2



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Newton's First and Second Laws

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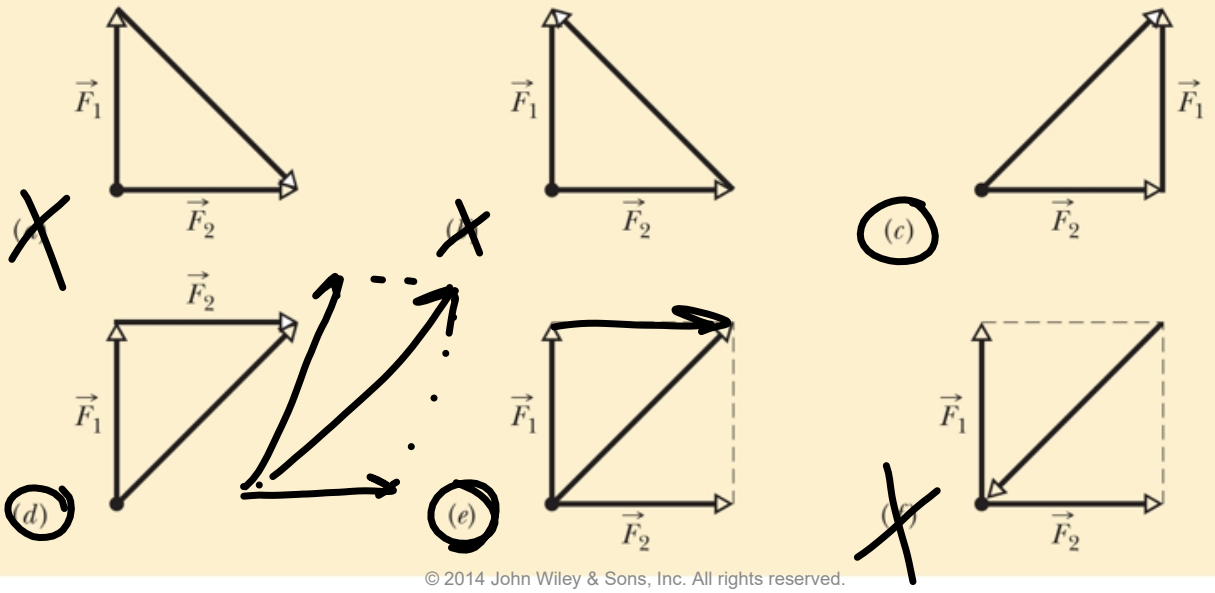
Checkpoint 1

Which of the figure's six arrangements correctly show the vector addition of forces $\vec{F}_1$ and $\vec{F}_2$ to yield the third vector, which is meant to represent their net force $\vec{F}_{net}$?



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Answer: (c), (d), (e)

5.3.1. A pipe is bent into the shape shown and oriented so that it is sitting horizontally on a table top. You are looking at the pipe from above. The interior of the pipe is smooth. A marble is shot into one end and exits the other end. Which one of the paths shown in the drawing will the marble follow when it leaves the pipe?

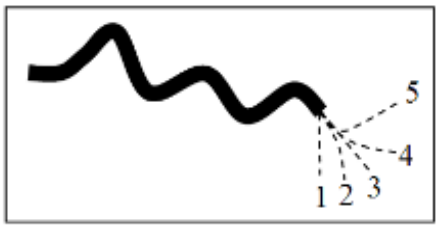
a) 1

b) 2

c) 3

d) 4

e) 5



ANS: C

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Newton's First and Second Laws

- What is mass?
  - > *"the mass of a body is the characteristic that relates a force on the body to the resulting acceleration"*
  - > Mass is a measure of a body's resistance to a change in motion (change in velocity)
  - > It is *not* the same as weight, density, size etc.
  - > Mass is inversely proportional to acceleration
  - > ONLY can sense it when trying to accelerate.

Example Apply an 8.0 N force to various bodies:

> Mass: 1kg → acceleration: 8 m/s2
> Mass: 2kg → acceleration: 4 m/s2
> Mass: 0.5kg → acceleration: 16 m/s2
> Acceleration: 2 m/s2 → mass: 4 kg

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5-5 Newton's First and Second Laws

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- Summarize these behaviors as:

- As an equation, we write: $\vec{F}_{\text{net}} = m\vec{a}$

Newton's Second Law: The net force on a body is equal to the product of the body's mass and its acceleration.

- Identify the body in question, and *only* include forces that act *on* that body!

$$F_{\text{net},x} = ma_x, \quad F_{\text{net},y} = ma_y, \quad \text{and} \quad F_{\text{net},z} = ma_z.$$

The acceleration component along a given axis is caused *only by* the sum of the force components along that *same* axis, and not by force components along any other axis.

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Newton's First and Second Laws

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- If the net force on a body is zero:
  - > Its acceleration is zero
  - > The forces and the body are in *equilibrium*
  - > *But* there may still be forces!
- Units of force:

Table 5-1 Units in Newton's Second Law (Eqs. 5-1 and 5-2)

System	Force	Mass	Acceleration
SI	newton (N)	kilogram (kg)	m/s^2
CGS[a]	dyne	gram (g)	cm/s^2
British[b]	pound (lb)	slug	ft/s^2

[a] $1\ dyne = 1\ g \cdot cm/s^2$.

[b] $1\ lb = 1\ slug \cdot ft/s^2$.

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5-1)

1.14 • Rear-end collision and whiplash injury

In a rear-end collision, a car is hit from behind by a second car. For decades, engineers and medical researchers sought to explain why the neck of an occupant of the front car is injured in such a collision. By the 1970s, they concluded that the injury was due to the occupant's head being whipped back over the top of the seat as the car was slammed forward, hence the common name "whiplash injury." The neck was apparently extended too far by the head's motion. As a result of this finding, head restraints were built into cars, yet neck injuries in rear-end collisions continued to occur. What actually causes these injuries?

Cool-down!

5.6.3 The graph shows the velocities of two objects as a function of time. During the intervals A, B, and C indicated, net forces $\vec{F}_A$, $\vec{F}_B$, and $\vec{F}_C$ act on the two objects, respectively. If the objects have equal mass, which one of the following choices is the correct relationship between the magnitudes of the three net forces?

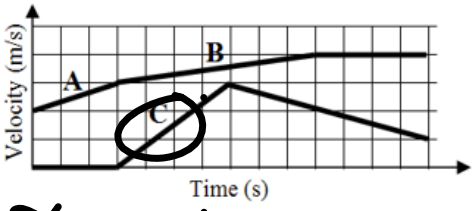
a) $F_A > F_B = F_C$

b) $F_C > F_A > F_B$

c) $F_A < F_B < F_C$

d) $F_A = F_B = F_C$

e) $F_A = F_C > F_B$



slope $\frac{dv}{dt} = a$ $F_{net} = ma$

ANS: B

Newton's First and Second Laws

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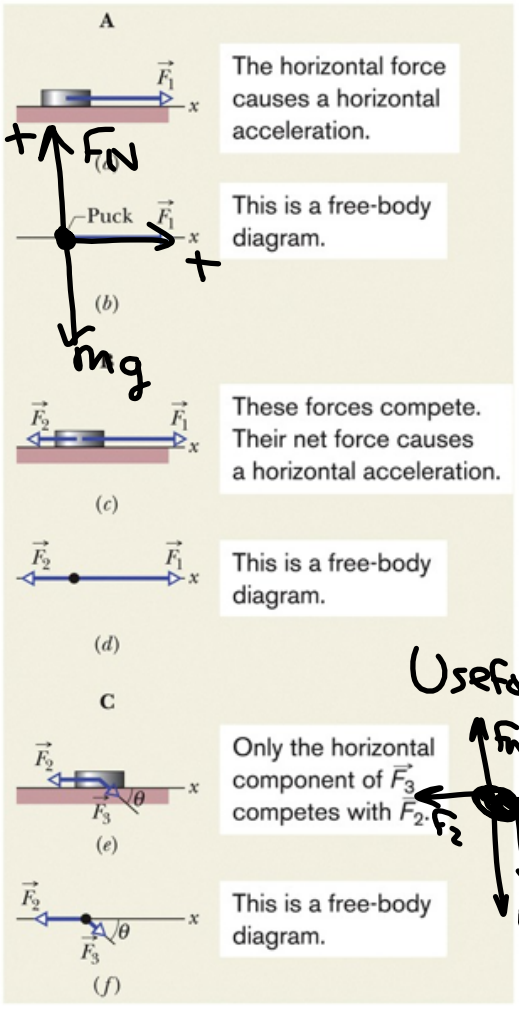
A
The horizontal force causes a horizontal acceleration.
This is a free-body diagram.
Puck
These forces compete. Their net force causes a horizontal acceleration.
This is a free-body diagram.
C
Only the horizontal component of $\vec{F}_3$ competes with $\vec{F}_2$.
This is a free-body diagram.

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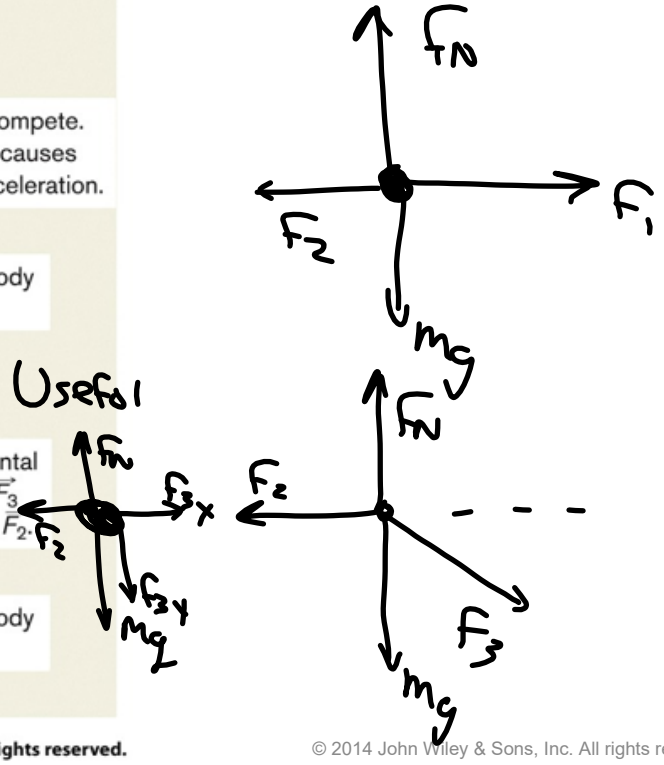
- To solve problems with forces, we often draw a **free body diagram**
- The only body shown is the one we are solving for
- Forces are drawn as vector arrows with their tails on the body
- Coordinate system shown
- Acceleration is NEVER part of a free body diagram – only forces on a body are present.



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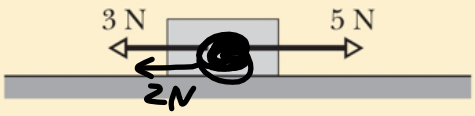
$F_{net_y} = ma_y$ $\vec{F}_{net} = m\vec{a}$ $F_{net_x} = ma_x$

$0 = m0$

Checkpoint 2



The figure here shows two horizontal forces acting on a block on a frictionless floor. If a third horizontal force $\vec{F}_3$ also acts on the block, what are the magnitude and direction of $\vec{F}_3$ when the block is (a) stationary and (b) moving to the left with a constant speed of 5 m/s?

$a = 0$

Answer: F3 = 2 N to the left in both cases

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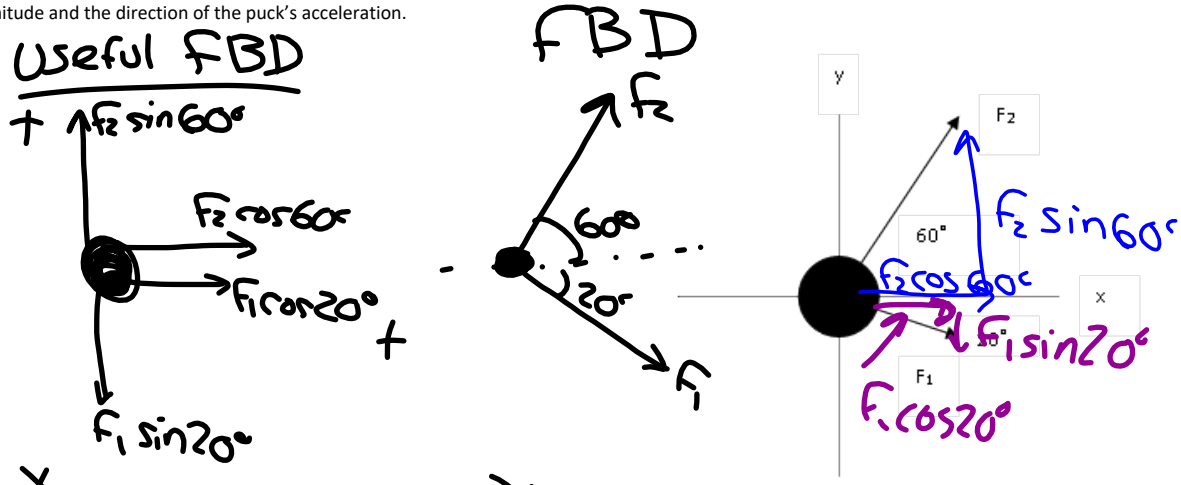
Example 1

A hockey puck having a mass of 0.30 kg slides on the horizontal, frictionless surface of an ice rink. Two hockey sticks strike the puck simultaneously, exerting forces on the puck shown below. The force $\mathbf{F}_1$ has a magnitude of 5.0 N, and the force $\mathbf{F}_2$ has a magnitude of 8.0 N. Determine both the magnitude and the direction of the puck's acceleration.



X

$F_{net} = ma$

$F_1 \cos 20° + F_2 \cos 60° = ma_x$

$5 \cos 20° + 8 \cos 60° = 0.3a_x$

$8.7 = 0.3a_x$

$a_x = 29 \text{ m/s}^2$

Y

$F_{net} = ma$

$F_2 \sin 60° - F_1 \sin 20° = ma$

$8 \sin 60° - 5 \sin 20° = 0.3a$

$5.22 = 0.3a$

$a = 17.4 \text{ m/s}^2$

$a = \sqrt{a_x^2 + a_y^2} = 33.8 \text{ m/s}^2$

$\theta = \tan^{-1}\left(\frac{17.4}{29}\right) = 30.96°$

Net

17.4

θ

29

Newton's First and Second Laws

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- A **system** consists of one or more bodies
- Any force on the bodies inside a system exerted by bodies outside the system is an **external force**
- Net force on a system = sum of external forces
- Forces between bodies in a system: **internal forces**
  - > Not included in a FBD *of the system* since internal forces cannot accelerate the system

Railroad engine and car. Towline pulls on front of engine, acts on whole statement.
Note: do not confuse a free body diagram of an entire system with free body diagrams of individual bodies within a system.

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5-6 Some Particular Forces

Learning Objectives

5.08 Determine the magnitude and direction of gravitational force on a mass, for a given free-fall acceleration.
5.09 Identify that weight is the magnitude of the net force required to prevent a body from falling freely, measured by the frame of ground.
5.10 Identify that a scale gives an object's weight when the measurement is done in an inertial frame but not in an accelerating frame, where it gives an apparent weight.

5.11 Determine the magnitude and direction of the normal force on an object when the object is pressed or pulled onto a surface.
5.12 Identify that the force parallel to the surface is a frictional force that appears when the object slides or attempts to slide.
5.13 Identify that a tension force is said to pull at both ends of a cord (or a cord-like object) when the cord is taut.

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5.6.5. A 912-kg car is being driven down a straight, level road at a constant speed of 31.5 m/s. When the driver sees a police cruiser ahead, she removes her foot from the accelerator. After 8.00 s, the speed of the car is 24.6 m/s, which is the posted speed limit. What is the magnitude of the average net force acting on the car during the 8.00 s interval?

a) 55.2 N

b) 445 N

c) 629 N

d) 787 N

e) 864 N

ANS: D

Warm-up

5.6.1. A car of mass m is moving at a speed 3v in the left lane on a highway. In the right lane, a truck of mass 3m is moving at a speed v. As the car is passing the truck, the driver notices that the traffic light ahead has turned yellow. Both drivers apply the brakes to stop ahead. What is the ratio of the force required to stop the truck over that required to stop the car? Assume each vehicle stops with a constant deceleration and stops in the same distance x.

a) 1/9
b) 1/3
c) 1
d) 3
e) 9

Force truck / Force car

$m_c = m$ $s_c = 3v$

$m_t = 3m$ $s_t = v$

c: $V = 0$, $V_0 = 3v$, $a =$, $\Delta x = x$, $t =$

t: $V = 0$, $V_0 = v$, $a =$, $\Delta x = x$, $t =$

$V^2 = V_0^2 + 2a\Delta x$

C: $0^2 = (3v)^2 + 2ax$

T: $0^2 = v^2 + 2ax$

e: $0 = 9v^2 + 2ax$

$\frac{-9v^2}{2x} = a$

$0 = v^2 + 2ax$

$\frac{-v^2}{2x} = a$

$F_{net} = ma$

$F = m\left(\frac{-9v^2}{2x}\right)$

$F = 3m\left(\frac{-v^2}{2x}\right)$

$\frac{-3mv^2}{2x} \div \frac{-9mv^2}{2x}$

$\frac{-3mv^2}{2x} \cdot \frac{2x}{-9mv^2} = \frac{3}{9} = \frac{1}{3}$

ANS: B

Warm-up

5.6.1. A car of mass m is moving at a speed 3v in the left lane on a highway. In the right lane, a truck of mass 3m is moving at a speed v. As the car is passing the truck, the driver notices that the traffic light ahead has turned yellow. Both drivers apply the brakes to stop ahead. What is the ratio of the force required to stop the truck over that required to stop the car? Assume each vehicle stops with a constant deceleration and stops in the same distance x.

a) 1/9

b) 1/3

c) 1

d) 3

e) 9

ANS: B

5-6 Some Particular Forces

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- The **gravitational force**:
  - > A pull that acts on a body, directed toward a second body
  - > Generally we consider situations where the second body is Earth
- In free fall (y direction, without considering air effect):

$$-F_g = m(-g)$$

- This force still acts on a body at rest!
- We can write it as a vector:

$$F_g = mg.$$

$$\vec{F}_g = -F_g\hat{j} = -mg\hat{j} = m\vec{g},$$

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5-6 Some Particular Forces

Weight : magnitude of net force required to prevent the body from falling freely.

The weight W of a body is equal to the magnitude F_g of the gravitational force on the body.

$$W = F_g \quad \text{(weight, with ground as inertial frame).}$$

$= mg$

Eq. (5-12)

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5-6 Some Particular Forces

- Measuring weight:
  - > Weight is not the same as mass: a pan balance will read the same for different values of *g*, a scale will read differently for different values of *g*
- Weight must be measured when the body is not accelerating vertically
  - > E.g., in your bathroom, or on a train
  - > But not in an elevator: apparent weight

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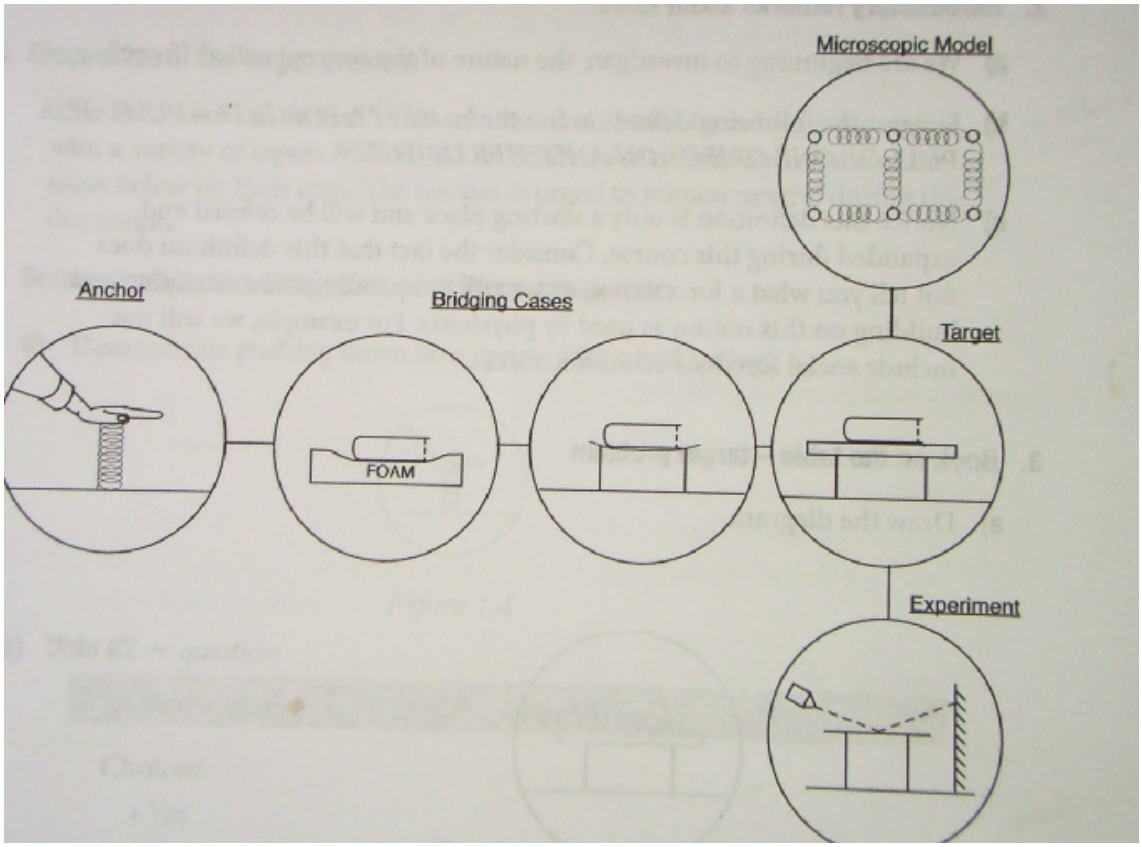
Does a surface apply a force?

Link attached


Microscopic Model
Anchor
Bridging Cases
Target
FOAM
Experiment

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5-6 Some Particular Forces

- The **normal force**:
  - > If you are standing on a surface, the push back **on** you from the surface (due to deformation) is the normal force
  - > Normal means perpendicular

When a body presses against a surface, the surface (even a seemingly rigid one) deforms and pushes on the body with a normal force $\vec{F}_N$ that is perpendicular to the surface.

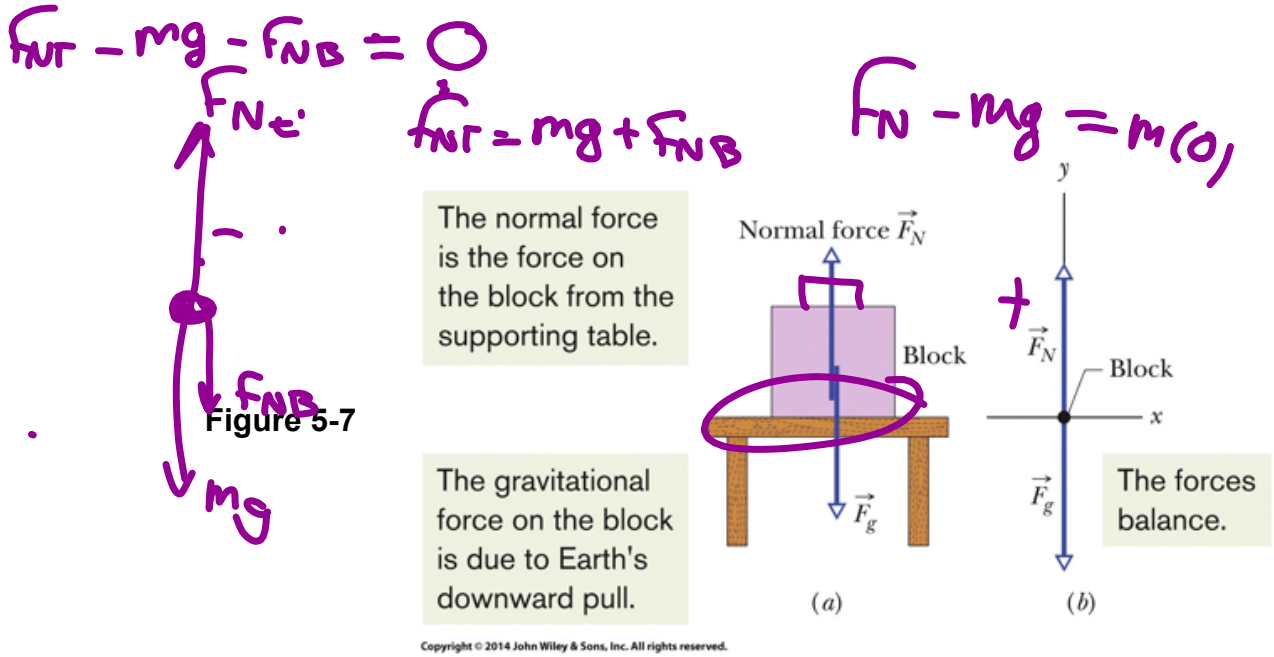

Figure 5-7

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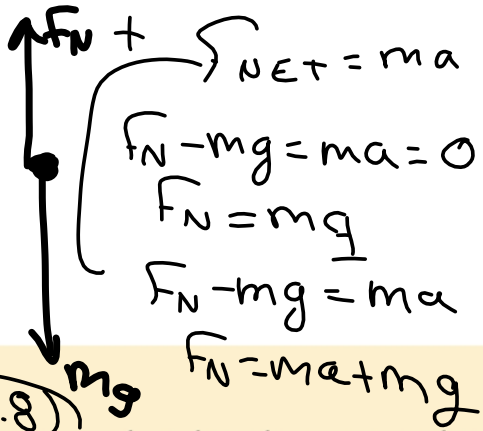
5-6 Some Particular Forces

Example **How do we find the normal force for a block of mass m that is resting on a table?**



Checkpoint 3

In Fig. 5-7, is the magnitude of the normal force F_N greater than, less than, or equal to mg if the block and table are in an elevator moving upward (a) at constant speed and (b) at increasing speed?

Answer: (a) equal to *mg* (no acceleration)
(b) greater than *mg* (, with positive acceleration)

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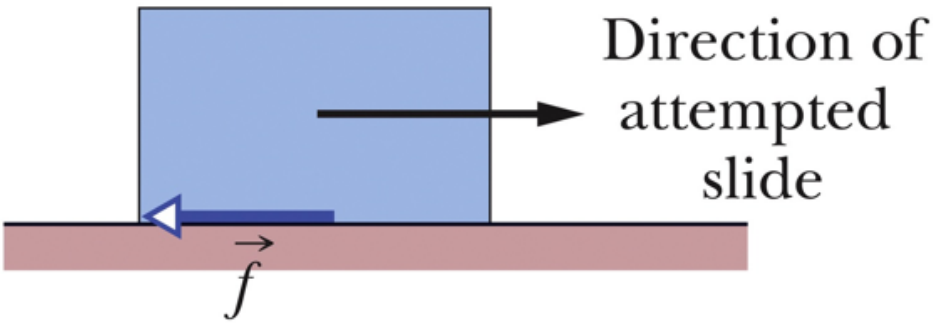
5-6 Some Particular Forces

- **Frictional force** or **friction**: We will revisit this!
  - > Occurs when one object slides or attempts to slide over another
  - > Directed along the surface, opposite to the direction of intended motion



5-8

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5-6 Some Particular Forces

- **Tension force**: Notation T
  Present with a cord, string, ...
  - > A cord (or rope, etc.) is attached to a body and pulled taut
  - > Cord pulls on the body with force *T* directed along the cord
  - > The cord is said to be *under tension*
  - > The tension in the cord is *T*
- A *massless* and *unstretchable* cord exists only as a connection between two bodies
  - > It pulls on both with the same force, *T*
  - > True even if the bodies and cord are accelerating, and even if the cord runs around a *massless, frictionless pulley*
  - > These are useful simplifying assumptions

Assumptions: • Cord doesn't have slack
• cord is massless

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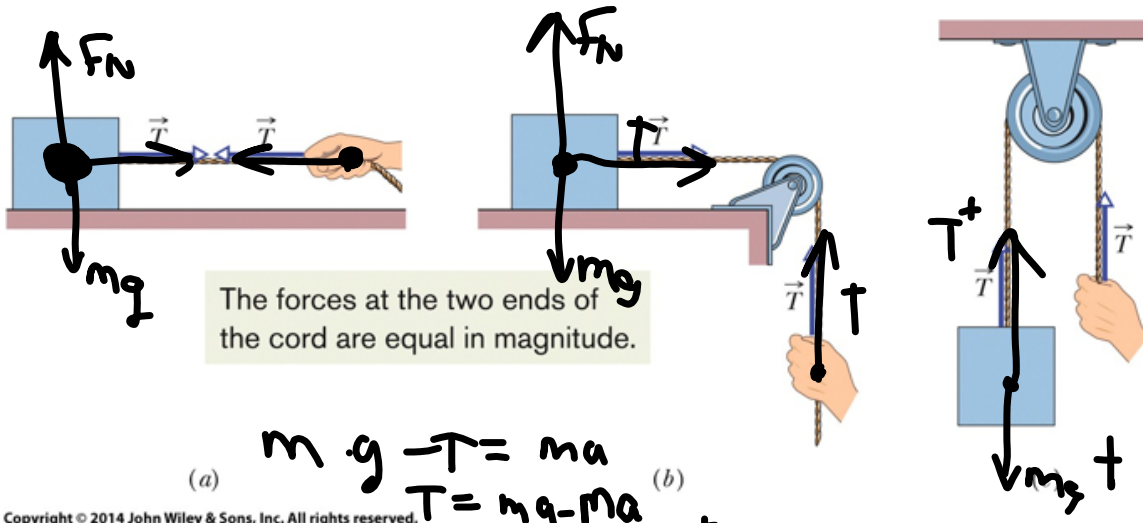
5-6 Some Particular Forces



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Checkpoint 4

The suspended body in Fig. 5-9*c* weighs 75 N. Is T equal to, greater than, or less than 75 N when the body is moving upward (a) at constant speed, (b) at increasing speed, and (c) at decreasing speed? Consider the direction of acceleration.

Answer: (a) equal to 75 N (b) greater than 75 N (c) less than 75 N

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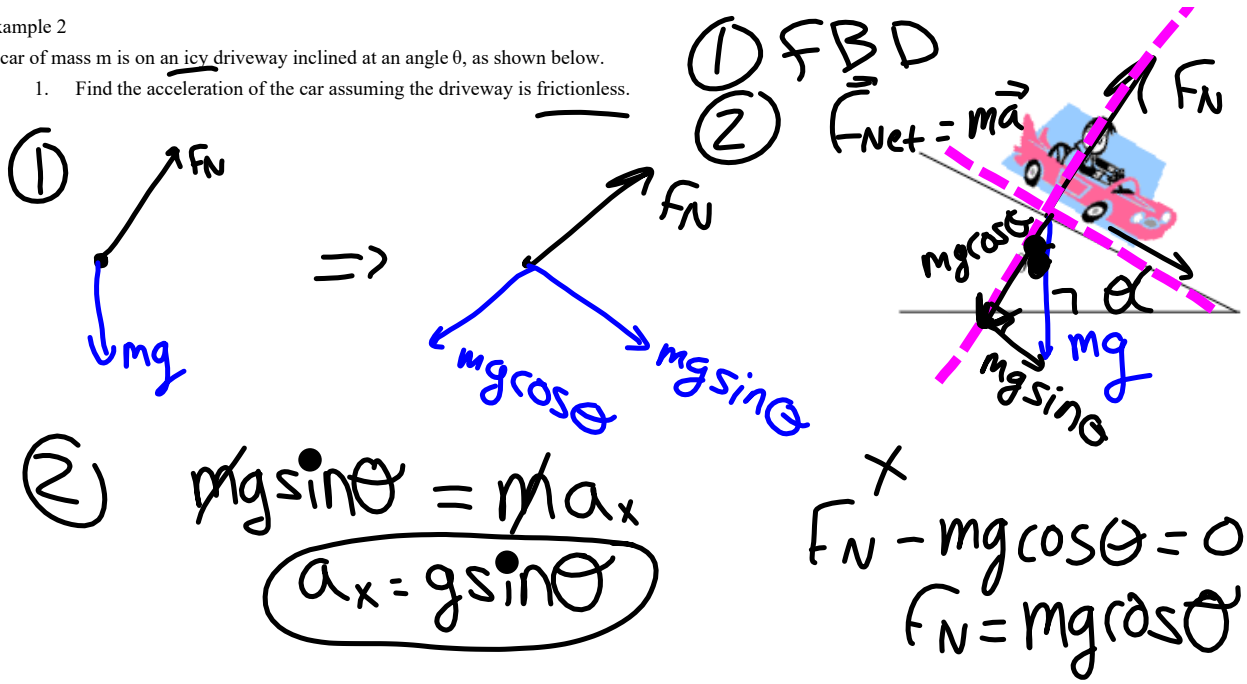
Example 2

A car of mass m is on an icy driveway inclined at an angle θ, as shown below.

1. Find the acceleration of the car assuming the driveway is frictionless.



② $mg\sin\theta = ma_x$

$a_x = g\sin\theta$

$\times$

$F_N - mg\cos\theta = 0$

$F_N = mg\cos\theta$

1. Suppose the car is released from rest at the top of the incline, and the distance from the car's front bumper to the bottom of the incline is d. How long does it take the front bumper to reach the bottom, and what is the car's speed as it arrives there?

$v_0 = 0$

$\Delta x = d$

$a = g\sin\theta$

$v = ?$

$t = ?$

$v^2 = v_0^2 + 2a\Delta x$

$v^2 = 2g\sin\theta\, d$

$\Delta x = v_0 t + \frac{1}{2}at^2$

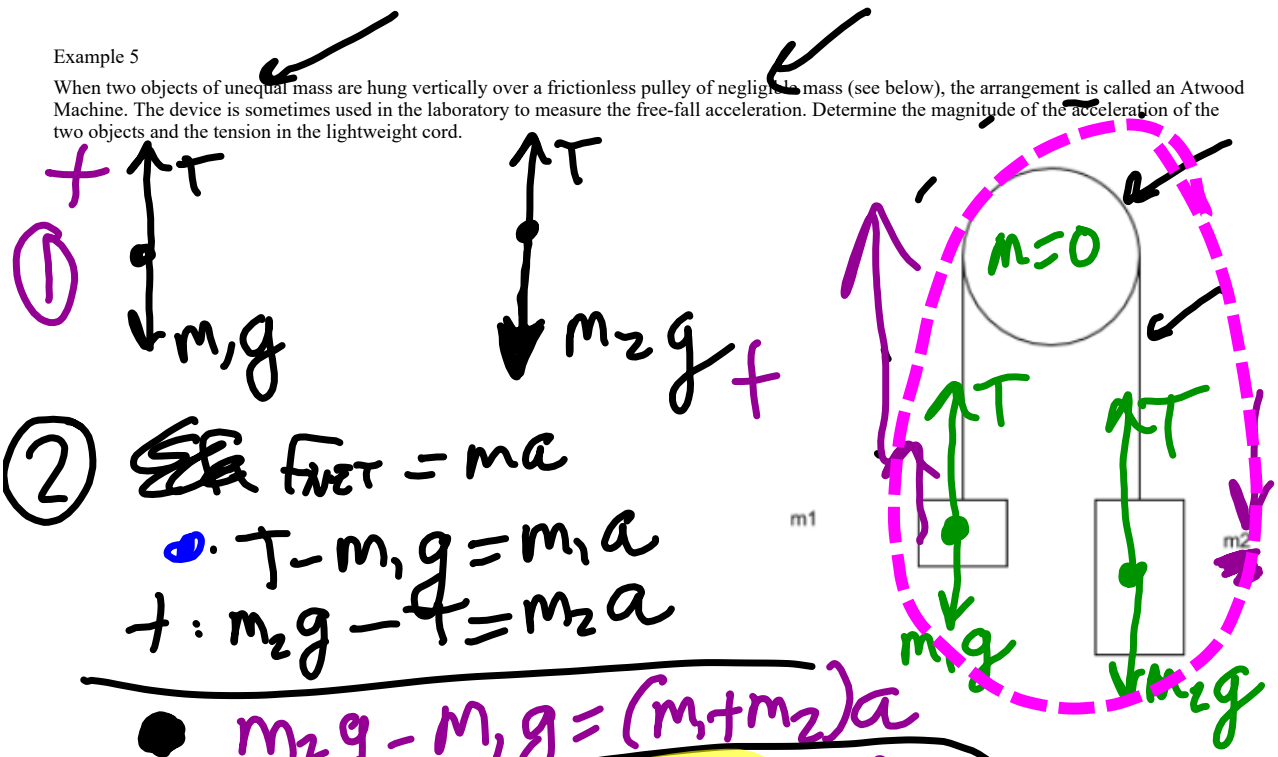
$d = \frac{1}{2}g\sin\theta\, t^2$

$t = \sqrt{\frac{2d}{g\sin\theta}}$

$v_{x_f} = \sqrt{2gd\sin\theta}$

Example 5

When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass (see below), the arrangement is called an Atwood Machine. The device is sometimes used in the laboratory to measure the free-fall acceleration. Determine the magnitude of the acceleration of the two objects and the tension in the lightweight cord.



① $+$ T, $m_1 g$; T, $m_2 g$ $+$

② $F_{NET} = ma$

• $T - m_1 g = m_1 a$

$+ : m_2 g - T = m_2 a$

• $m_2 g - m_1 g = (m_1 + m_2) a$

$$a = \frac{g(m_2 - m_1)}{(m_1 + m_2)}$$

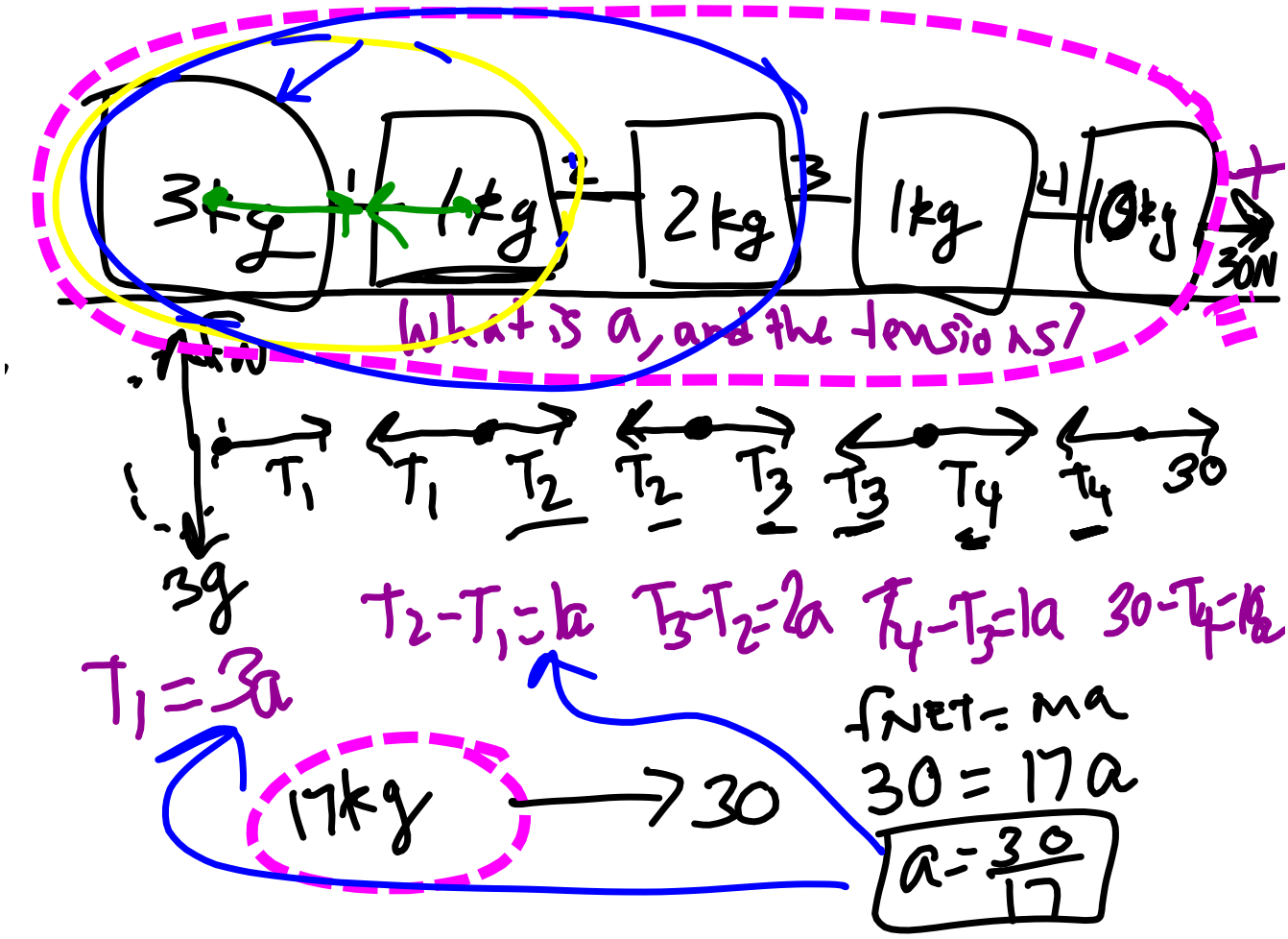
$$T = m_1 a + m_1 g = m_1 (a + g)$$

$$= m_1 \left(\frac{g(m_2 - m_1)}{m_1 + m_2} + g \right) \quad \cdot 1 = \frac{m_1 + m_2}{m_1 + m_2}$$

$$= m_1 g \left(\frac{m_2 - m_1 + m_1 + m_2}{m_1 + m_2} \right)$$

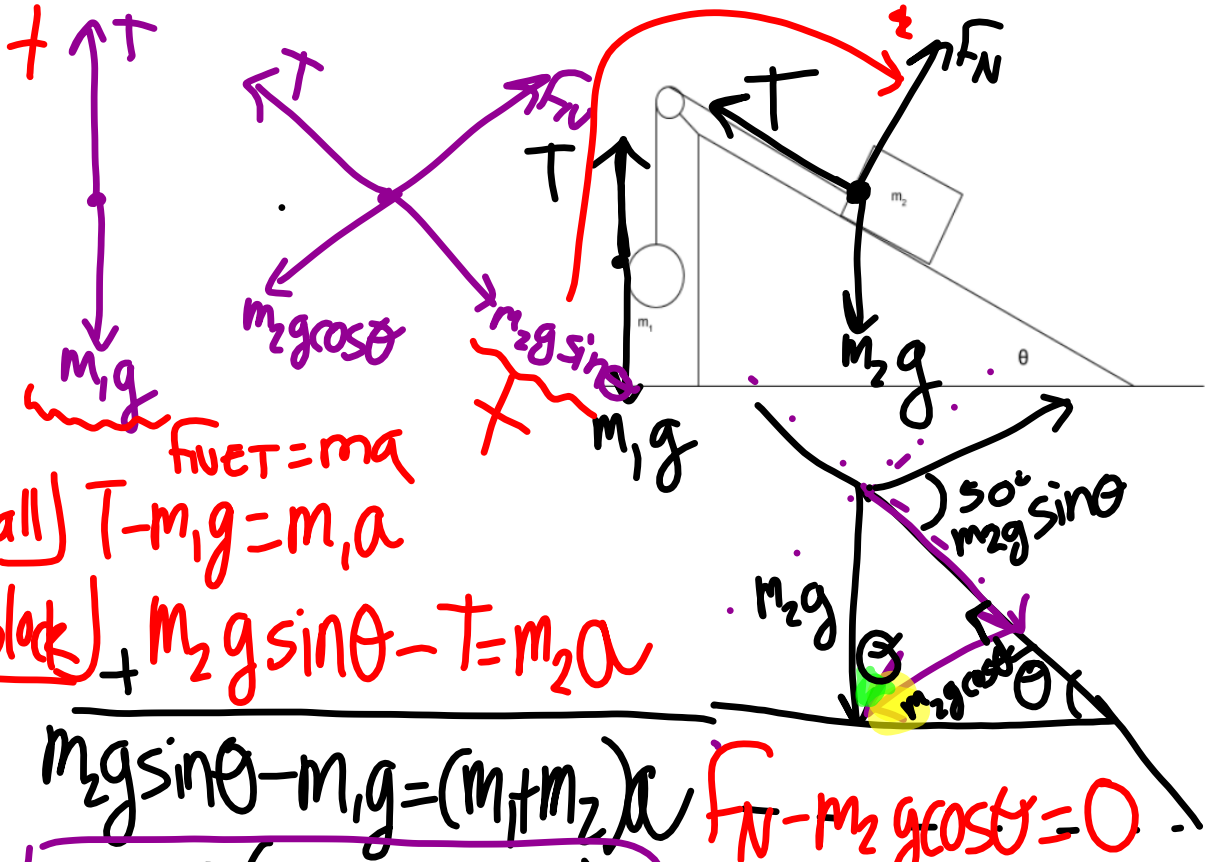
$$T = \frac{2 m_1 m_2 g}{m_1 + m_2}$$

$$\frac{m_1 g}{1} \left(\frac{2 m_2}{m_1 + m_2} \right)$$


3kg
1kg
2kg
1kg
10kg
30N
What is a, and the tensions?
T1
T1
T2
T2
T3
T3
T4
T4
30
3g
T2-T1=1a
T3-T2=2a
T4-T3=1a
30-T4=10a
T1=3a
17kg
30
FNET=ma
30=17a
a=30/17

Example 6

A ball of mass m_1 and a block of mass m_2 are attached by a lightweight cord that passes over a frictionless pulley of negligible mass. The block lies on a frictionless incline of angle θ. Find the magnitude of the acceleration of the two objects and the tension in the cord.



ball) $T-m_1g=m_1a$

block) $+\ m_2g\sin\theta-T=m_2a$

$m_2g\sin\theta-m_1g=(m_1+m_2)a$

$$a=\frac{g(m_2\sin\theta-m_1)}{m_1+m_2}$$ abs. value

$F_N-m_2g\cos\theta=0$

$F_N=m_2g\cos\theta$

$$T=m_1a+m_1g=m_1\frac{g(m_2\sin\theta-m_1)}{m_1+m_2}+m_1g$$

$$=m_1g\left(\frac{m_2\sin\theta-m_1}{m_1+m_2}+1\right)=m_1g\left(\frac{m_2\sin\theta-m_1+m_1+m_2}{m_1+m_2}\right)$$

$x\ y+x=x(y+1)$

$$=m_1g\left(\frac{m_2\sin\theta+m_2}{m_1+m_2}\right)=m_1m_2g\left(\frac{1+\sin\theta}{m_1+m_2}\right)$$

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5-7, 5-8 Third Law, Applying Newton's Laws

Learning Objectives

5.14 Identify Newton's third law of motion and third-law of force pairs.
5.15 For an object that moves vertically or on a horizontal or inclined plane, apply Newton's second law to a free-body diagram of the object.
5.16 For an arrangement where a system of several objects moves rigidly together, draw a free-body diagram and apply Newton's second law for the individual objects and also for the system taken as a composite object.

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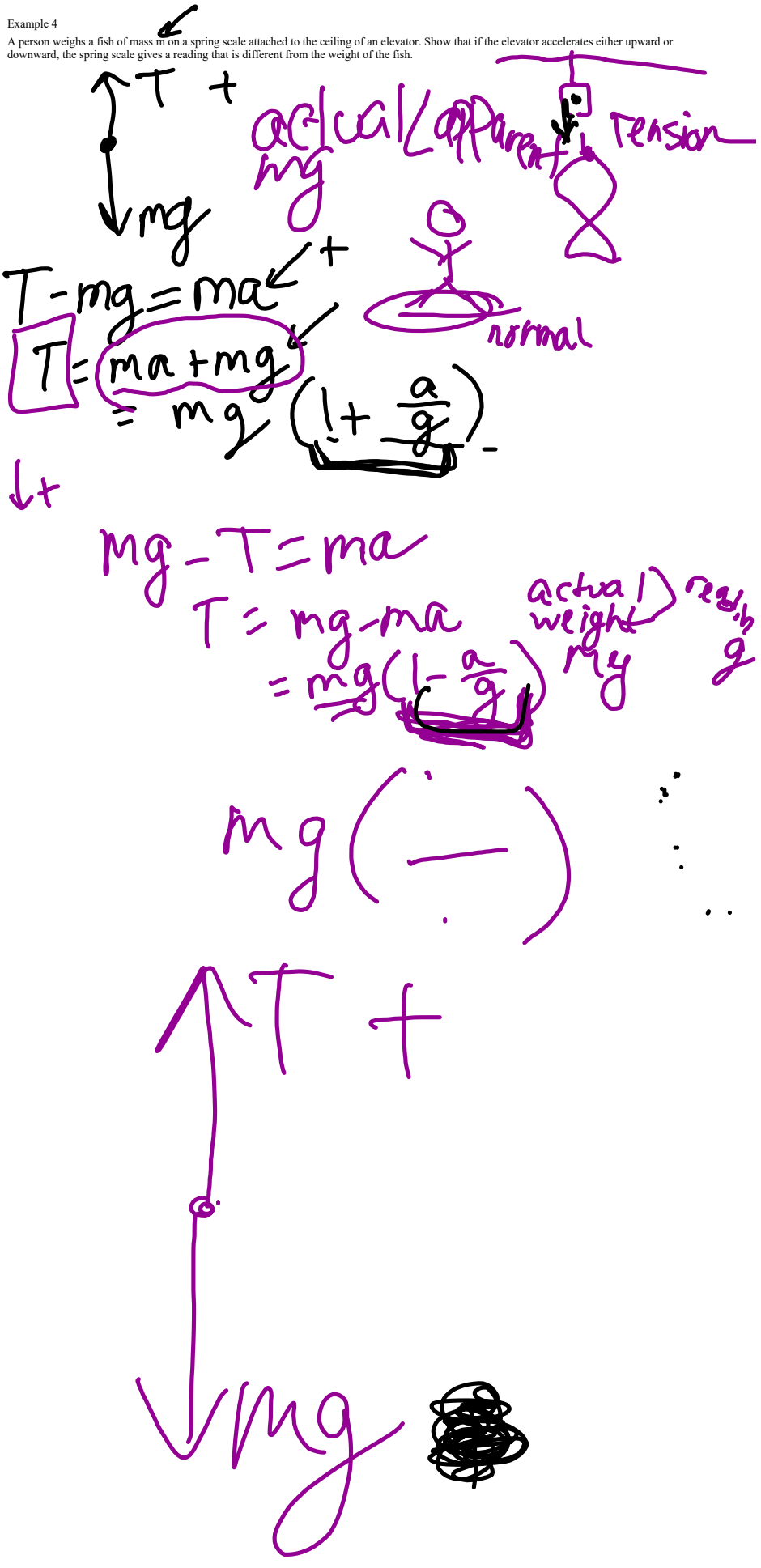
Example 4

A person weighs a fish of mass m on a spring scale attached to the ceiling of an elevator. Show that if the elevator accelerates either upward or downward, the spring scale gives a reading that is different from the weight of the fish.



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5-7 Newton's Third Law

- Objects *interact* when they push or pull on each other:

Newton's Third Law: When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

- We can write this law as a scalar or vector relation:

$$F_{BC} = F_{CB} \qquad \vec{F}_{BC} = -\vec{F}_{CB}$$

- We call these two forces a **third-law force pair**
- Any time any two objects interact, there is a third-law force pair

Notation: F_{AB} is the force on A from B

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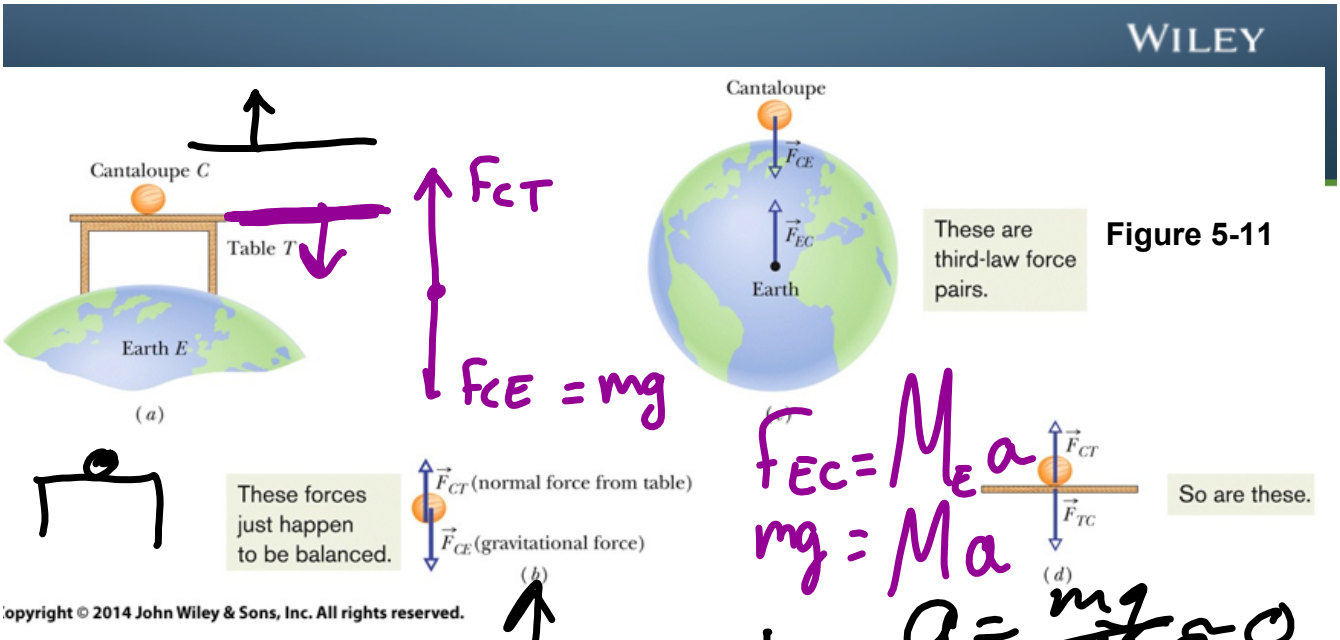

Figure 5-11

- Third-law force pairs: $\vec{F}_{CT} = -\vec{F}_{TC}$ (cantaloupe–table interaction).

$$\vec{F}_{CE} = -\vec{F}_{EC} \quad \text{(cantaloupe–Earth interaction).}$$

- This includes the gravitational forces between Earth and the cantaloupe!

  > Then why does the earth not appear to be accelerating from the cantaloupe?

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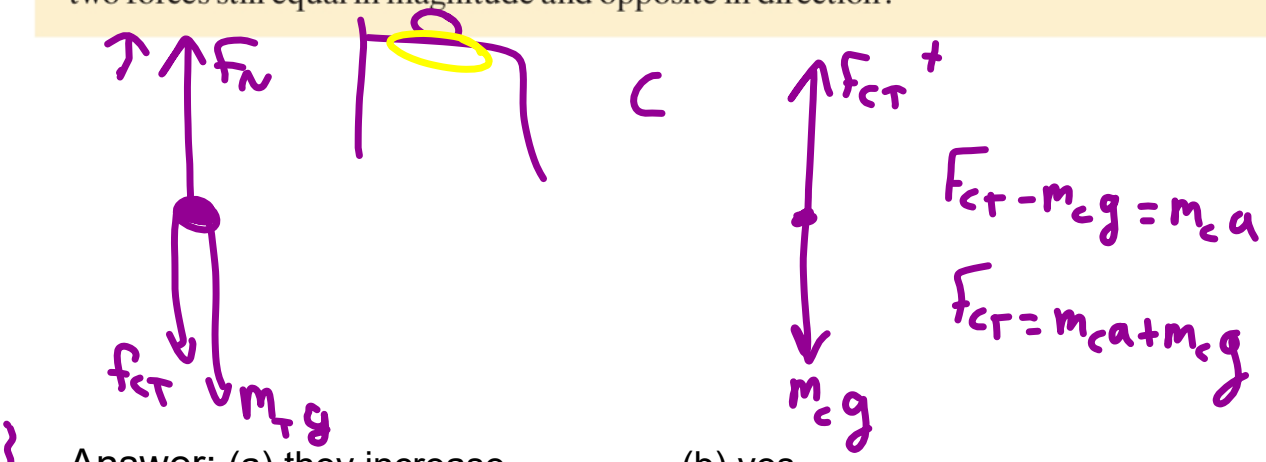
5-7 Applying Newton's Laws

Checkpoint 5

Suppose that the cantaloupe and table of Fig. 5-11 are in an elevator cab that begins to accelerate upward. (a) Do the magnitudes of $\vec{F}_{TC}$ and $\vec{F}_{CT}$ increase, decrease, or stay the same? (b) Are those two forces still equal in magnitude and opposite in direction? (c) Do the magnitudes of $\vec{F}_{CE}$ and $\vec{F}_{EC}$ increase, decrease, or stay the same? (d) Are those two forces still equal in magnitude and opposite in direction?



Answer: (a) they increase (b) yes
(c) they begin to decrease slowly (the gravitational force of Earth decreases with height—negligible in an actual elevator)
(d) yes

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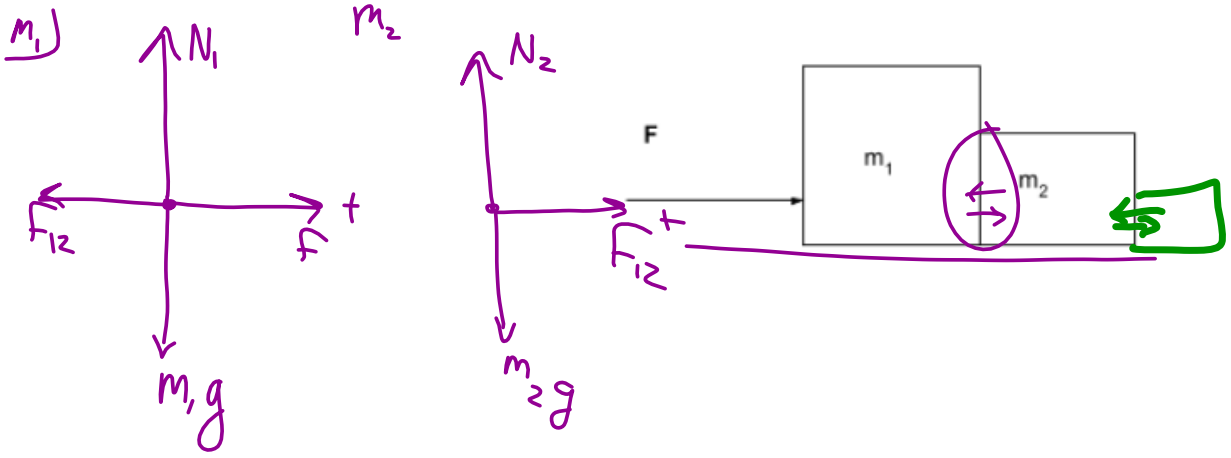
Example 3

Two blocks of masses m1 and m2, with m1>m2, are placed in contact with each other on a frictionless, horizontal surface. A constant horizontal force F is applied to m1 as shown.

1. Find the magnitude of the acceleration of the system.
2. Determine the magnitude of the contact force between the two blocks.



$F - F_{12} = m_1 a$

$+ \quad F_{12} = m_2 a$

$F = (m_1 + m_2)a$

$a = \frac{F}{m_1 + m_2}$

$N_1 - m_1 g = 0$

$N_2 - m_2 g = 0$

$F_{12} = m_2 \left(\frac{F}{m_1 + m_2} \right)$

$F_{12} = \frac{m_2 F}{m_1 + m_2}$

Example 3

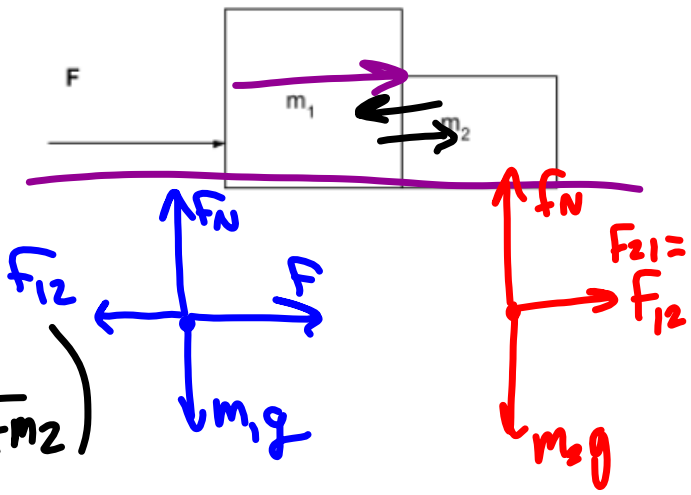
Two blocks of masses m1 and m2, with m1>m2, are placed in contact with each other on a frictionless, horizontal surface. A constant horizontal force F is applied to m1 as shown.

1. Find the magnitude of the acceleration of the system.
2. Determine the magnitude of the contact force between the two blocks.

a) $\Sigma F = (m_1+m_2)a_x$

$a_x = \frac{F}{m_1+m_2}$

$f_{12} = m_2 a = m_2\left(\frac{F}{m_1+m_2}\right)$



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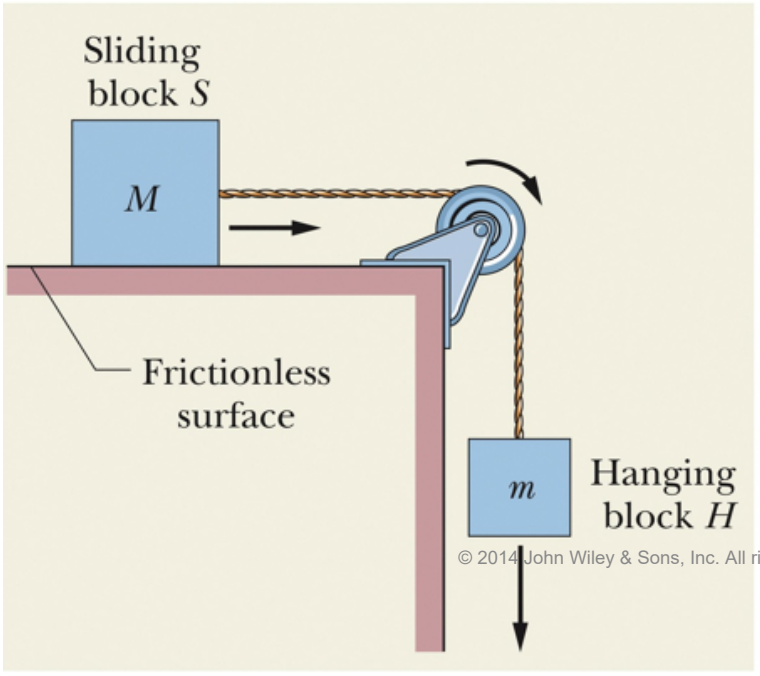
5-8 Applying Newton's Laws

Sample Problem A block of mass M = 3.3 kg, connected by a cord and pulley to a hanging block of mass m = 2.1 kg, slides across a frictionless surface



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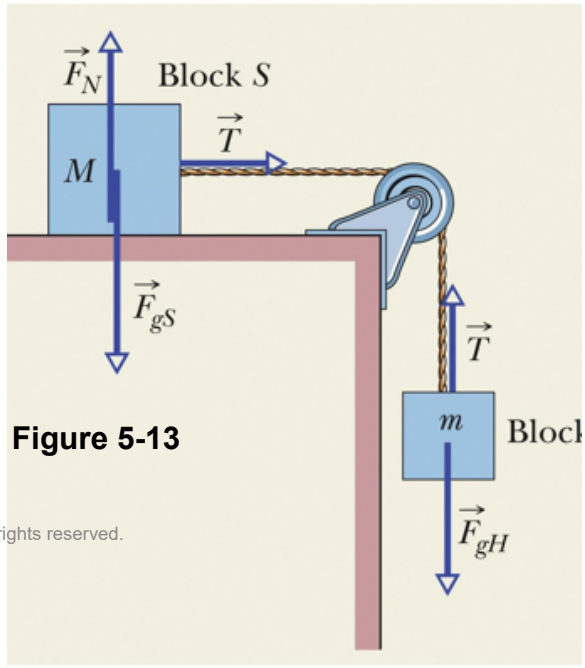

Figure 5-13

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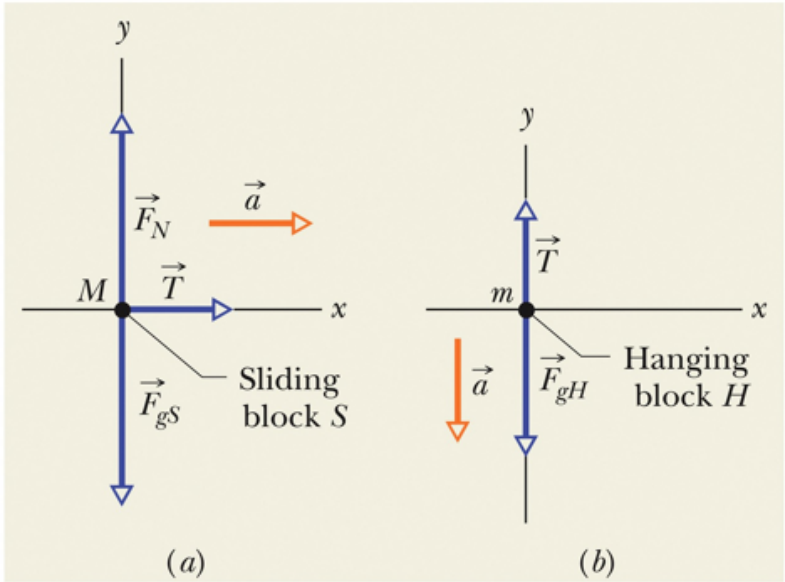
Draw a free body diagram!



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5-8 Applying Newton's Laws

- Draw the forces involved
- Treat the string as unstretchable, the pulley as massless and frictionless, and each block as a particle

- Draw a free-body diagram for each mass
- Apply Newton's 2nd law ($F = ma$) to each block → 2 simultaneous eqs.
- Eliminate unknowns (T) that are the same, and solve for the acceleration

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Figure 5-14

5-3 Applying Newton's Laws

- For the sliding block: $T = Ma.$
- For the hanging block: $T - mg = -ma.$ Eq. (5-18)
- Combining we get: $T = \frac{Mm}{M + m} g.$

$$a = \frac{m}{M + m} g.$$

- Plugging in we find a = 3.8 m/s2 and T = 13 N
- Does this make sense? Check that dimensions are correct, check that a < g, check that $T < mg$ (otherwise acceleration would be upward), check limiting cases (e.g., g = 0, M = 0, m =))

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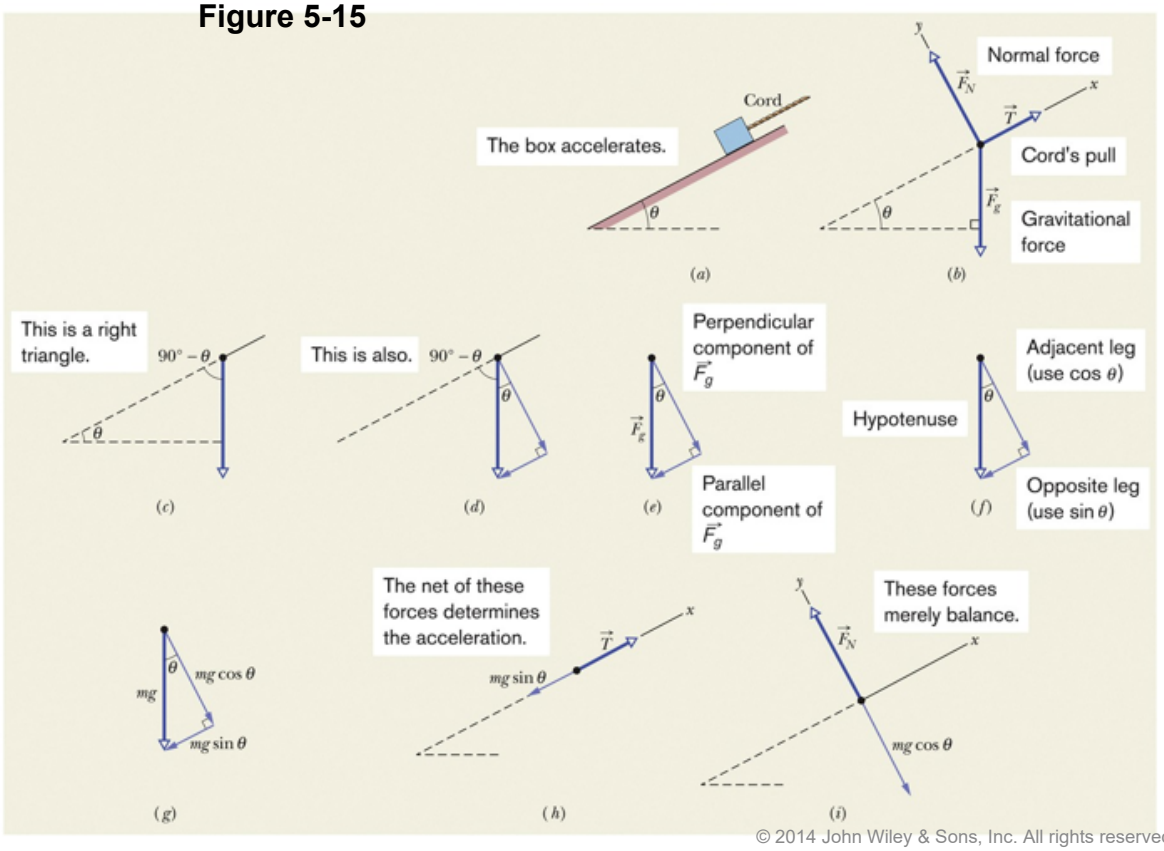
5-3 Applying Newton's Laws

Sample Problem A block being pulled up a ramp:

Figure 5-15



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5 Summary

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Newtonian Mechanics

- Forces are pushes or pulls
- Forces cause acceleration

Force

- Vector quantities
- 1 N = 1 kg m/s2
- Net force is the sum of all forces on a body

Newton's First Law

- If there is no net force on a body, the body remains at rest if it is initially at rest, or moves in a straight line at constant speed if it is in motion.

Inertial Reference Frames

- Frames in which Newtonian mechanics holds

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5 Summary

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Mass
- The characteristic that relates the body's acceleration to the net force
- Scalar quantity

Newton's Second Law
- Free-body diagram represents the forces on one object

Eq. (5-1)

$$\vec{F}_{\text{net}} = m\vec{a}$$

Some Particular Forces
- Weight: $W = mg$
- Normal force from a surface
- Friction along a surface
- Tension in a cord

Eq. (5-12)

Newton's Third Law
- Law of force-pairs
- If there is a force **by** *B* **on** *C*, then there is a force **by** *C* **on** *B*:

$$\vec{F}_{BC} = -\vec{F}_{CB}$$

Eq. (5-15)

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